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The Political Economy of a Soviet Military R&D Failure: Steam Power for Aviation, 1932 to 1939*

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Abstract

By studying a Soviet R&D failure, the prewar attempt to create a new aeroengine technology based on the steam turbine, we find out more about the motivations, strategies, and payoffs of principals and agents in the Soviet command economy. Alternative approaches to the evaluation of R&D failure are outlined. New archival documentation shows the scale and scope of the Soviet R&D effort in this field. The allocation of R&D resources resulted from agents' horizontal interactions within a vertical command hierarchy. Project funding was determined in a context of biased information, adverse selection, and agents' rent seeking. Funding was rationed across projects and through time. Budget constraints on individual projects were softened in the presence of sunk costs, but were hardened periodically. There is no evidence that rents were intentionally distributed through the Soviet military R&D system to win trust or reward loyalty; the termination of aviation steam power R&D in 1939 despite the sunk costs they represented was timely.

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The Political Economy of a Soviet Military R&D Failure: Steam Power for Aviation, 1932 to 1939

The Soviet economy was managed by a vertical hierarchy in which agents supplied principals with flows of information from below and principals issued commands from above. Commands flowed downward, but the more closely we study this system the more we find that self-interested agents rarely did exactly as they were told. Some horizontal transactions among agents that were ordered did not take place, and others took place without being ordered or even when they were prohibited. Information flowed upwards but the most difficult problem for those who received it was to verify exactly what people were really doing when they appeared to be obeying commands.

In this paper I explore the relationship between the Soviet vertical command hierarchy and the horizontal interactions of agents through the prism of an R&D failure. This was the Soviet attempt to create a new aeroengine technology using steam power. It was a serious venture that consumed significant resources for a few years and provides a relatively self-contained episode for studying the motivations and calculations that drove the R&D process.

What is an R&D failure? All research may produce new knowledge of both explicit and tacit kinds, and generates externalities that are potentially of benefit to society. In this paper I define failure narrowly within a principal-agent framework: an R&D project fails even though it yields a return to society, if it does not generate a surplus for the funding principal from the useful application that the principal intended. Thus I will classify Soviet investment in steam power for aviation as an R&D failure even though it may have enhanced human knowledge and generated all sorts of useful spinoffs.

The economic significance of R&D failures can be considered from three perspectives. R&D failure may be analysed within a profit-seeking framework as a cost to an economic principal, within a rent-seeking framework as consumption by an economic agent, and within a political economy framework as a channel through which a political principal may distribute rewards to loyal agents.

In considering R&D as a profit-seeking activity it is useful to distinguish the structure of competition between and within nations. In general R&D can be motivated by both “profit” and “competitive threat”.¹ From a national perspective each country pursued its defence objectives as a strategic competitor in relation to other nations. Military technologies provided the means to these objectives, and investments in military R&D made the technologies more efficient. By investing in technological enhancement each nation could expect to realise its strategic goals at less cost when the military technology of other states were controlled, i.e. even if others did not engage in military R&D. This is the profit motive. The second motive arose from knowing that its rivals were also engaging in military R&D: the nation that fell behind might fail to maintain its strategic position and be beaten, i.e. lose ownership rights over its assets to a competitor. This motive is the competitive threat.

The dimension of competitive threat gave the process of interwar military R&D its character of a technological race between the great powers. At the same time competitive threat did not overwhelm the profit motive. If it had, a nation that fell behind the leader would have lost any incentive to invest in trying to come second. In military aeroengineering we see that each great power invested substantial resources

¹ For this distinction see Beath, Katsoulacos and Ulph (1995).

in those areas where it was not the technological leader; it was an R&D success to come first, but it was not a failure to come second or third; it was only a failure to come nowhere. One reason for this is that the decisive advances came too late in the war to be decisive in combat. Another reason is that some of the new knowledge produced by R&D did not become common knowledge because a part was kept secret, and some of the rest remained tacit and could only be acquired through “learning by doing”.² Thus, Germany was the first power to create jet aircraft, and was able to exploit an advantage over its enemies as a result, but the British and Russians rationally maintained their efforts to come next.

The structure of competition within each country created the same motivations in a different balance. Within the British, German, and Soviet markets for military invention individual agents also faced a profit motive and a competitive threat. Think of the returns to R&D success as partly financial and partly reputational. In terms of reputation the *only* thing that mattered was to come first: for example each country now remembers its own pioneer of the jet aeroengine, Frank Whittle, Hans von Ohain, and A.M. Liul’ka, while their rivals are completely forgotten. Much more than between countries, the competition within each country took the form of a race into which each rival was drawn by the chance to scoop the winnings before the others.

Other than in terms of reputation, none of the jet pioneers was allowed to make a profit from realising their dream. In Britain the first contracts for serial production of jet engines were given to Rolls Royce, deliberately sidelining Whittle’s company Power Jets, and in Germany to Junkers and BMW, favouring the rivals of Ohain’s sponsor Otto Heinkel. For different reasons Soviet arrangements gave designers no expectation of a stake in the producer profits arising from their inventions. This might even have been a good thing: economic theory has shown that, when the pool of potential inventions is limited, winner-takes-all may lead rival agents to invest in R&D until all the potential gains have been competed away.³

The approach outlined so far treats investments in military R&D as a cost to a profit-seeking principal. Since R&D outcomes were uncertain there were many potential projects each with a high probability of individual failure. Principals had to be willing to fund many projects in order to ensure that at least some successful projects would be included. Thus, failed inventions were part of the cost of success.⁴

Within a rent-seeking framework military R&D is not only an investment cost to the principal but also a source of the agent’s consumption. Therefore, military R&D may become a focus for self-interested rent-seekers. Several factors encourage it: the cloak of military secrecy; relatively soft budget constraints; intrinsic uncertainty about the timescale and expected value of returns to investment that impede selection, including the rational expectation that many projects will fail; and large information biases that impede monitoring. Under these circumstances R&D agents can be expected to invest resources in lobbying to win project funding, and some of the resources they invest will be diverted from nominal allocations to military R&D.

Thus R&D failures may have another significance. From the point of view of the principal R&D failures were simply part of the cost of success: some experiments

² On tacit knowledge see MacKenzie (1996), 215–16, and on learning by doing Arrow (1962).

³ Dasgupta and Stiglitz (1980).

⁴ Mokyr (1990), 176–7. Sah and Stiglitz (1986) have suggested that, for given incentives and a given distribution of good and bad projects, a polyarchic market system in which screening decisions are decentralised and screening intensity is endogenous should possess an advantage relative to a unified hierarchy. Therefore, a prevalence of bad projects under a hierarchy may be a cost of maintaining that hierarchy. However, this hypothesis cannot be pursued through a single case study.

fail, and failed experiments are part of the necessary background against which success is achieved. In contrast, from the point of view of rent-seeking agents unsuccessful projects provided consumption nearly as effectively as successful ones. From this perspective R&D failures may be a gain to the agent although a loss to the principal. Why then should agents pursue success for the principal? Agents' indifference to failure might also be strengthened if reputational capital created by past success could not be translated into higher income.

Finally, within a political economy framework, in the presence of rent-seeking a political principal such as a dictator may deliberately design the allocation system to enable transactions in the political market place, for example to distribute gifts to agents in return for loyalty.⁵ For example, in a study of Soviet regional policy James Harris has shown that Stalin used investment allocations to reward loyal agents in the regions in his struggle with the opposition in the late 1920s; during the 1930s, however, his regional agents were called to account for their uses of these resources.⁶ Valery Lazarev and Paul R. Gregory have shown in a detailed study of the Soviet allocation system for motor vehicles in the 1930s that the dictator maintained a stock of vehicles in reserve for use as rewards for loyal agents.⁷

If the budgetary system is used to reward loyal agents, the effect must be that budgetary outlays will exceed an efficient level. The excess is the signal that loyalty is expected in return: if some waste did not result, those receiving the funding would have no reason to offer thanks to the government in exchange since any politician would rationally promise to undertake at least those expenditures that were efficient.⁸ If the system for military procurement and R&D were used in this way, then some R&D failures might be the intended outcome of a political exchange through which both agent and principal gained: the agent gained consumption and the principal gained loyalty, which is one source of political power.

In short, the incidence of R&D failures may reflect an economic experimentation process in which a certain proportion of failures is an unintended but necessary consequence, or it may reflect an economic process in which opportunistic agents extract rents from a funding principal, or it may reflect an intention on the part of a political principal to compensate agents directly for their loyalty. To discriminate between these hypotheses in the case of Soviet military R&D requires a close study of the decision making process, and this is one purpose of the analysis that follows.

I explore this process through the documentary records of the Soviet defence industry held by the Russian State Economics Archive (RGAE), supplemented by those of the Red Army held by the Russian State Military Archive (RGVA), both in Moscow. What these records make possible is a detailed analysis of Soviet research and development in terms of the problem of the principal and the strategies adopted by both principals and agents. Before the archives our interpretation of the management of defense resources was based on accounts that largely denied the existence of this problem. Anodyne official histories presented a version from the standpoint of the principal, say, the Politburo and defense industry leaders, which denied the existence of the problem, the divergence of the agent's interests from those of the principal. The memoirs and biographies of the agents, the producers, designers, and scientists presented a more interesting and truthful account, but from a self-interested perspective that, while honestly reporting the tensions and disagreements among principals and agents as they actually occurred, tended to attribute such problems to the principals' low education, lack of trust, excessive interference, and

⁵ Wintrobe (1998), 150–3.

⁶ Harris (1999).

⁷ Lazarev and Gregory (2000).

⁸ Wintrobe (1998), 31.

oppressive behaviour towards those of superior culture and understanding, i.e. the agents.⁹ Through the archives we can come to a more rounded understanding, observing the rules of the game and the strategies of the players from both sides.

This paper is about invention, not innovation. A substantial scholarly literature has demonstrated that in Soviet industry innovation was sluggish because risks were high and rewards were meagre.¹⁰ Inventiveness, in contrast, was everywhere but even when successful it often did not benefit society. Joseph Berliner distinguished between activities aimed at maximising technological objectives, which he called “mission oriented”, and activities aimed at maximising an economic surplus. He suggested that, while Soviet R&D organisations were good at accomplishing technological missions regardless of cost, they were poor at organising economic activities to the benefit of society.¹¹ In this paper I hope to show that in the Soviet economy mission oriented activity was also “economic activity” in the sense that everyone involved was looking for a payoff, and the costs they were willing to incur or impose on others depended on the private stakes.¹²

The paper is in five parts. Part 1 sets the idea of aviation steam power in the context of early twentieth century aeroengineering. Part 2 outlines the dimensions of the Soviet R&D effort in this field in the 1930s. Part 3 describes the vertical and horizontal relationships within which decisions were taken to initiate and continue or terminate projects, and part 4 sets out the options open to agents to mount and resist competitive threats to and from each other. Part 5 analyses the problem faced by the funding principals in distinguishing between good and bad projects. Part 6 concludes.

1. Problems and Solutions

Despite a number of major postwar studies of the comparative development of Soviet technology in various fields, a scholarly history of Soviet aircraft propulsion has yet to be written.¹³ Before the revolution aeroengineering barely existed in Russia and in the early years of Soviet power it remained the “Achilles heel” of Soviet aviation.¹⁴ The establishment of a modern industry began in the mid-1920s with the importation and adaptation of French, German and British engines to the conditions of Soviet industry. Subsequently the Soviet Union quickly established its own industry with a substantial manufacturing capacity. Between 1936 and 1938 five factories produced an annual average of more than 15 000 engines of the conventional reciprocating type with an airscrew propeller, including radial and in-line, air- and water-cooled, petrol and diesel fuelled, and supercharged models.¹⁵ However, continuously challenged by the rapidity of technological advance in other countries, the Soviet industry remained

⁹ For example Holloway’s (1984) path-breaking study of Soviet atomic science.

¹⁰ Especially Berliner (1976), Amann, Cooper, and Davies (1977), Amann and Cooper (1982), and Amann and Cooper (1986).

¹¹ Berliner (1976), 506–9.

¹² Applied more generally this approach may eventually lead to new comparisons with military-industrial planning and procurement processes in market economies, including the United States, but the necessary analysis is still at a preliminary stage. See Harrison (2001a) and Gregory (2002).

¹³ Sutton (1968, 1971, 1973), Amann, Cooper, and Davies (1977), Hanson (1981), Amann and Cooper (1982), Amann and Cooper (1986), and Albrecht (1993) are among the most important studies with a more general focus or providing specific Soviet-western comparisons in other fields.

¹⁴ Sobolev (1996), 30.

¹⁵ For serial production figures see Kostyrchenko (1992), 429.

dependent on imitation and adaptation of foreign designs and did not establish an autonomous capacity for development of conventional engines.¹⁶

In the interwar period aircraft performance neared the limits of the piston and propeller engine.¹⁷ The mechanical efficiency of propellers was found to fall away beyond a point as rotation speeds increased, with the result that propeller-driven aircraft could never approach supersonic speeds or stratospheric altitudes. Piston engines also required frequent and intensive maintenance and had short service lives. Such limitations prompted intensive efforts in several European countries to develop completely new types of aeroengine based on a continuous thermal cycle giving rise to a jet reaction. In Great Britain, Germany, and the Soviet Union much effort was invested in two alternatives: the rocket motor and the jet engine.¹⁸

The rocket principle had been well understood for hundreds of years, and European armies had used small, solid-fuelled rockets on the battlefield since the Napoleonic era. The new fuels and heat-resistant materials being developed in the early twentieth century promised significant applications for the rocket principle in aviation propulsion. However, to create a primary rocket motor for aviation still implied a design of unprecedented size and complexity by interwar standards, depending on more powerful liquid fuels with substantial further advances in material and fuel sciences and control systems. At the end of the development process lay apparatuses that could attain extraordinary speeds and limitless altitudes but with fuel consumption at rates that limited powered flight to a few minutes' duration.

The concept of the jet engine was of more recent origin. Earlier designs could not provide a primary power plant because they could not be ignited unless the aircraft was already moving at flight speed. Later designs such as the turbojet made this defect good at the cost of added complexity including moving parts rotating at very high speeds and temperatures; these could not be brought into reality without still greater advances on interwar benchmarks in terms of heat-resistant alloys, fuels, and the control of combustion.

Hindsight tells us that by the end of World War II the turbojet would solve the problem of high-speed, high-altitude aviation. Liquid-fuelled rocketry, while not the answer for aviation, would solve other problems of strategic bombardment and space travel. During the interwar period this outcome was not yet clear and several avenues that would later be seen as stopgaps or failures were also explored. Among these were various attempts to build a propulsion unit based on the steam turbine.

The basic scheme is shown in figure 1. It involved an oil-fired boiler to create steam; expansion of the steam in a turbine converted part of its thermal energy into kinetic energy that initially took the form of the torque required to rotate an airscrew propeller; the propeller drove an airstream backwards and the aircraft forwards. Since the aircraft in flight could not replace its water, the steam passed through a condenser before being returned to the boiler in a closed circuit. Additional refinements could include: using a multi-stage turbine to convert more of the overall steam pressure drop into useful energy; expanding the boiler's exhaust gases in a gas turbine to supercharge the boiler itself or to supplement the torque delivered to the propeller; using the heat otherwise lost from the condensing steam to expand the cooling air in such a way as to add to the overall thrust. At least one experimental Soviet design

¹⁶ Albrecht (1993), 28–32.

¹⁷ Grigor'ev (1994), 189.

¹⁸ Soviet rocketry before and during World War II has been investigated by Ordway and Sharpe (1979), Holloway (1982b), Siddiqi (2000) and, with the benefit of new archival documentation, Harrison (2000). On the early development of the Soviet jet aeroengine see Harrison (2001b).

also introduced a mercury boiler so as to utilise its higher temperature limits as a preliminary stage to a steam turbine.¹⁹

Figure 1. The Steam Turbine in an Aviation Propulsion Unit

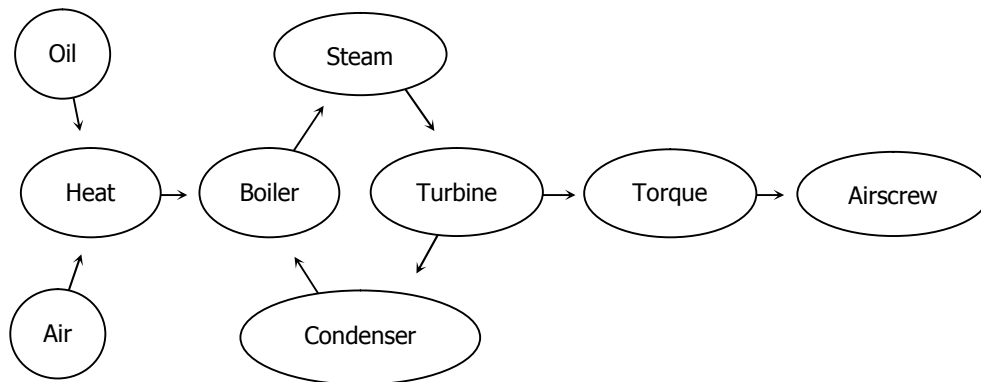
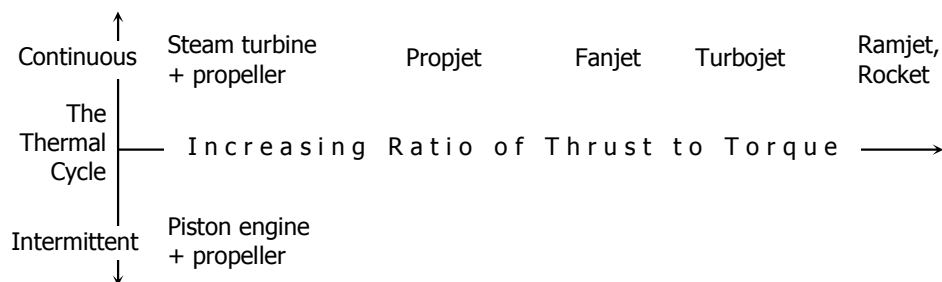


Figure 2 arranges the spectrum of modern aeroengines in two dimensions. Along the vertical axis the technologies of more recent development that make use of a continuous thermal cycle are demarcated from the traditional technology that relied on the intermittent action of reciprocating pistons. Along the horizontal axis the proportion of the energy that is delivered in the form of a jetstream, or thrust, rather than of torque to a propeller or turbine rises from zero to infinity.

Figure 2. Where the Steam Turbine Engine Fits



The steam turbine lies at the most conservative extreme of the range of continuous thermal cycle engines, in that it aimed to deliver torque more efficiently and reliably rather than replace torque by thrust. This meant that the steam turbine, even if it worked, would never give access to supersonic speeds or stratospheric altitudes. Its main advantage lay in offering to replace the reciprocating engine with a continuous cycle using a familiar technology that operated quietly and reliably for long periods at moderate temperatures and rates of rotation, with less destructive vibration and fire hazard, using materials that were already available and cheaper fuels.

Only hindsight makes the concept of steam-driven propulsion for aircraft appear surprising. Between the development of the steam locomotive and the advent of the light petrol engine there were many projects for steam-powered flight. Charles Parsons, who invented the steam turbine in 1884, also successfully tested a model steam aeroplane in 1893.²⁰ In the interwar period steam turbines were widely used in

¹⁹ The principle of the mercury boiler, first applied in the United States by General Electric in 1914, was evaluated briefly by Stodola (1927), 1313–16.

²⁰ Gibbs–Smith (1970), 70; see also chapters 5 to 9 and especially pages 59–68.

naval propulsion, their other main use being in electric power generation. Historically the gas turbine came after the steam turbine and arose from the latter, so it was the steam turbine that was already the more proven technology.²¹ The first inquiry on these lines was carried out in the United States by the Navy Department Bureau of Engineering in 1922.²² Others followed not only in America but also in Britain, France, and Germany. In the 1930s, however, as will become apparent, it seems likely on present information that more aviation steam power projects were being pursued in the Soviet Union than in the rest of the world put together.

If steam turbines replaced the reciprocating engine at sea, then why did this not happen in the air as well? The main problem was that existing land- and ship-based applications of the steam turbine were based on ratios of power to weight and volume that were too low to take to the air. They required not only large boilers but also bulky condensers to convert steam back to water; these could scarcely be accommodated within an airframe light enough to be lifted into the air by the power that the turbine would develop.²³ Improving power relative to the mass of the engine and its fuel was therefore the main focus of aviation-related development efforts.

2. Scale and Scope

Table 1 provides an overview of the main Soviet R&D projects in aviation steam turbines from 1932 to 1939. It is compiled from plans, reports, and memoranda of the commissariats of defence, heavy industry, the defence industry, and the aircraft industry. The table shows that in the prewar years there were eleven major projects involving eleven research establishments; the association between projects and establishments was not very tidy since some designers had more than one institutional affiliation through time or even contemporaneously. This compares with seven or eight projects in the rest of the world at the time. There were five main funding interests: the Red Army air force, the civil aviation authority, the Academy of Sciences, the aircraft industry, and the electricity generation industry.²⁴ There were three urban centres of activity where four designers accounted for three fifths of the 34 project-years in total: S.A. Aksiutin and N.M. Sinev in Moscow, P.L. Kozhevnikov in Leningrad, and V.T. Tsvetkov in Khar'kov.

The time profile of these projects is illustrated in figure 3. Officially work began in 1932. Between then and the end of 1937 ten projects were initiated. Four of them had been curtailed already by the end of 1936, so the number of major projects in progress peaked at the end of 1937 at six. Five of those were cancelled during 1938 and, although one more was begun during 1939, all had been abandoned by 1940.

How did the scale of Soviet resources compare with efforts being made in other countries? The evidence of British, German, and Soviet sources is that there were nine major steam turbine ventures in the interwar and early war years: four were sponsored in Germany by AEG, Hüttner, Vorkauf, and Wagner; four in the United States by the U.S. Navy Department, William Brobeck, a group around the helicopter

²¹ Voronkov (1984), 115.

²² Knörnschild (1941), 369. I thank Jean Vezina for this reference and Godfrey Carr for his translation of it from German.

²³ Liul'ka and Kuvshinnikov (1981), 88.

²⁴ The involvement of the electricity generation industry might be construed as an attempt to extract rents from new uses for an existing technology in which it had a vested interest. In a similar case Henning and Trace (1975), 385, attribute the British interwar slowness to adopt diesel engines for marine propulsion in preference to steam turbines partly to "the over-optimistic performance claims by builders of steam-turbine machinery". I thank Stephen Broadberry for this reference.

pioneer Igor Sikorsky at the United Aircraft Corporation, and a partnership of the Great Lakes Aircraft and General Electric Corporations; two in France by Béchar and Breguet Aviation; and one in Britain by Aero-Turbines Ltd.²⁵ Brobeck was a former engineer of the Besler Corporation and the Besler engine, although not a turbine, is also worthy of note as the first and only steam engine to succeed in powering flight. Besler, having acquired Doble Steam Motors in 1931, had developed a compact 150 horse-power steam reciprocating engine for use in rail and road transport. Installed in a light aircraft it took to the air on 12 April 1933, and this attracted the attention of the Soviet government; further information is given in the Appendix. Leaving the Besler engine to one side, however, it would appear by this crude standard that the ten Soviet projects matched the ten in the rest of the world of the 1930s.

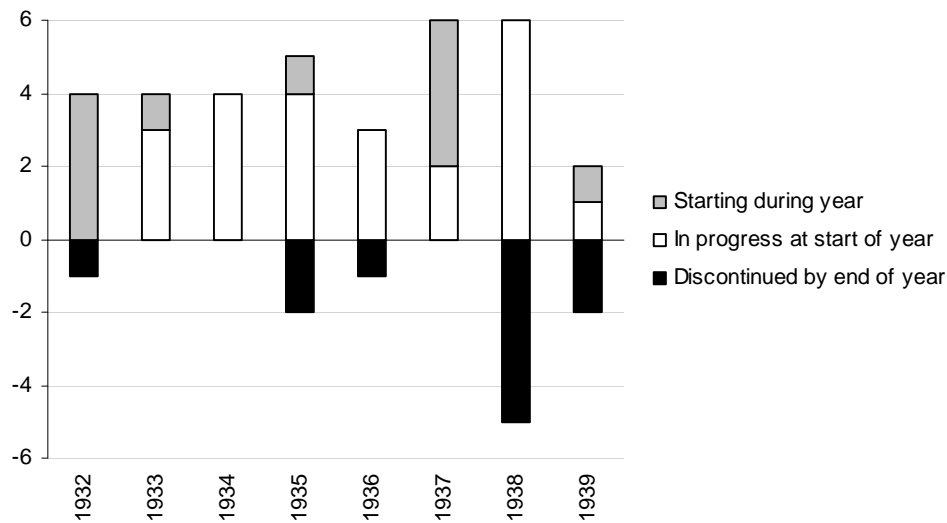
Did the Soviet effort represent a significant commitment of national resources? On the information available at present, the answer appears to be no. At the end of 1937, acting director Sinev of the special-purpose design bureau (SKB) of the commissariat of the defence industry put the total of sunk costs of the various steam turbine projects so far at 20 million rubles over five and a half years, i.e. not more than four million rubles per year.²⁶ On the basis of an annual average wage for that period of 3000 rubles, four million rubles would also represent the direct-plus-indirect employment of up to 1300 public-sector workers. Included in this total were a few scientists and designers who were more highly paid and were a particularly scarce resource, but even 100 such specialists would have represented no more than one per thousand of the Soviet Union's stock of "scientific workers" in 1940.²⁷

²⁵ The most complete survey is provided by Knörschild (1941); a subsequent British wartime survey by Smith (no date), 36–40, appears to take much of its information from Knörschild while adding details of work in progress at Breguet and United Aircraft. A Soviet memorandum of 28 February 1937 (RGAE, 8328/1/919, 77) precedes both of these. It lists seven foreign steam turbine projects belonging to AEG, Wagner, Hüttner, Vorkauf, Bessler, Doble, and General Electric–Great Lakes Aircraft; thus it correctly identified four that would feature in Knörschild's later list, added one (AEG), omitted five (Béchar, Brobeck, United Aircraft, Breguet, and Aero-Turbines, but the last three did not exist in 1937) and wrongly included Besler and Doble, which was a single venture and not a turbine. It may be asked how much Soviet information about these developments relied on espionage. Details of the GEC–Great Lakes Aircraft project and the Besler engine were already in the public domain; see Collina (1932), another reference for which I thank Jean Vezina, and the Appendix. There is no indication of the sources of Soviet information about the German projects, which became well known subsequently through Knörschild (1941) except for that of AEG concerning which nothing further is known.

²⁶ RGAE, 8328/1/992, 15 (19 December 1937).

²⁷ There were 98 300 "scientific workers" in the Soviet Union in 1940 according to Goskomstat (1987), 64.

Figure 3. Soviet Aviation–Related R&D in Steam Turbines, 1932 to 1939: Numbers of Major Projects



Source: calculated from table 2.

Although insubstantial in absolute terms, the Soviet interwar effort in the direction of aviation steam power represented a measurable proportion of overall Soviet military R&D resources; these are known only for 1936 and 1937, and were as follows (in million rubles):²⁸

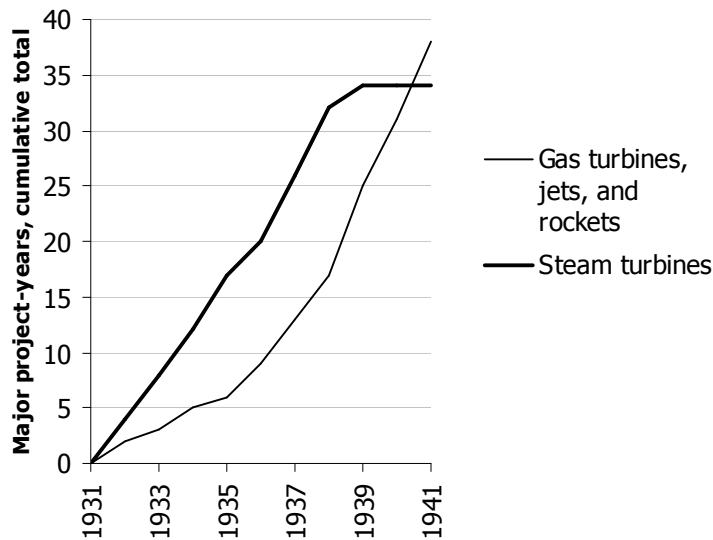
	Plan	Actual
1936	119	88
1937	136	67

Thus 4 million rubles a year represented 3 per cent of resources budgeted for military R&D in these years, and 5 per cent of resources used.

What is also to the point is that Soviet funding of steam power plants for aviation probably exceeded that channeled into the much more famous projects for gas turbines, jets engines, and rockets. Table 2 shows that in every year between 1932 and 1938 at least as many and usually more steam turbine projects were in progress than the number of jet propulsion projects. Only in 1939 did efforts in jet propulsion begin to overshadow the steam turbine projects as the cull of the latter got under way. Consequently, as figure 4 shows, the cumulative investment of Soviet R&D resources in steam turbines, measured in major project–years, was overtaken by that in jet propulsion only in 1941.

²⁸ Harrison and Davies (1997), 387. These figures in turn represented less than two per cent of total military equipment orders.

Figure 4. Soviet Aviation–Related R&D in Steam Turbines Versus Gas Turbines, Jets, and Rockets, 1931 to 1941: Cumulative Investments in Major Project–Years



Source: calculated from table 2.

The technical variation among steam turbine project designs was considerable. Kozhevnikov's "gas–steam" apparatus evidently made use of the boiler's exhaust gases in an auxiliary turbine. Przheslavskii's "binary–cycle" turbine used a high–temperature liquid, probably mercury, in an auxiliary boiler. Design capacities ranged from a few hundred horse–power to Tsvetkov's first monster, rated at 15 000 horse–power but never built. By comparison, the largest reciprocating aeroengines in serial production in the Soviet Union and elsewhere at the end of the 1930s somewhat exceeded 1000 horse–power.²⁹

The performance characteristics that mattered most were specific weight and specific fuel consumption, both measured relative to capacity. These are not always reported in the documentation, but available figures are shown in table 3. Variation was considerable, but the typical design proposed a 3000 horse–power engine with a specific weight of 1 kilogramme per horse–power and specific fuel consumption around 300 grammes per horse–power per hour of operation.³⁰

The specific weight of the steam turbines was generally not as good as that of contemporary piston engines. For example, the design weight of the Mikulin M–34 mass–produced in the mid–1930s was 0.8 kilogrammes per horse–power.³¹ Moreover,

²⁹ Other steam power aeroengine projects not considered here include work on the "Besler System" at the Moscow Aviation Institute (MAI), discussed in the Appendix, and a plan, evidently soon abandoned, to build a steam–turbine supercharger for a reciprocating aeroengine in 1932–3 at the Khar'kov Aviation Institute (KhAI) and under the Red Army Bureau of New Designs (BNK); see Rodionov (2002), 1932 under September (Sovnarkom decree on the construction of steam turbine engines), and 1933 under 17 January (Unshlikht to STO) and 23 March (Almazov to Gosplan).

³⁰ For comparison the steam turbine being developed by GEC for Great Lakes Aircraft in the late 1930s weighed 3.17lbs (1.44 kilogrammes) per horse–power and also consumed 0.67lbs (300 grammes) of fuel per horse–power per hour at full power; see Collina (1932).

³¹ Rodionov (2002), 1934 under 3 July.

the specific weight of piston engines was falling. The M-34 and Klimov M-105, the Wright Cyclone and its Soviet derivative the M-25, and the Rolls Royce Merlin, all weighed in at 0.6 to 0.7 kilogrammes per horse-power in their last versions of the prewar period.³²

Specific fuel consumption can also be compared, although comparison is complicated by the fact that piston engines burnt high-octane petroleum rather than the low-grade fuel oil used by a steam boiler.³³ In the mid-1930s the design consumption of the mass-produced M-34 in its RN and FN versions was 255 grammes of aviation spirit per horse-power per hour.³⁴ For a cross-check consider the reported performance data of the 1936 version of the four-engined TB-7 heavy bomber, the aircraft that some designers had in mind for a steam turbine: these imply a figure that was only slightly higher at 300 grammes per horse-power per hour.³⁵ Table 3 suggests that the more fuel-efficient steam turbines were competitive with this. They also used a much cheaper and more readily available fuel, so regardless of specific fuel consumption they offered immediate gains in ruble operating costs.

Ultimately, lower running costs did not compensate for the sheer mass of steam turbine engines, including the mass of fuel. Thus the ruble cost of fuel required was a less important limit on performance than its weight. A TB-7 with its fuselage rearranged to accommodate boiler and turbine and its wings filled by condensers had little space remaining for fuel, crew, or payload.

3. Project Finance

3.1. Rationing, Rivalry, and Budget Constraints

What limited Soviet outlays on steam propulsion R&D? Stalin's Politburo set cash limits on ministerial budgets from year to year, but detailed allocation was delegated to officials at or below the level of minister. The main problem these officials faced was technological uncertainty: R&D agents presented them with many proposals for long-term projects, one of which would eventually solve the problem of aviation propulsion for the next half century, but no one knew which one. Rationing was an appropriate response. Funding was rationed across new projects, and was also rationed through time for established projects. As a result, R&D agents competed for both initial funding and subsequent refinancing. Making limited allocations to many projects permitted funding principals to exploit the rivalry of the agents and, by monitoring the progress of competing projects, to use each to provide information about the others and thus learn about their true worth. And by rationing funding through time principals could monitor the cumulative progress of each project

³² Grigor'ev (1992), 86, 90, 93.

³³ According to Jasny (1952), 151-2, the official wholesale prices of fuel oil in Leningrad and of grade 2 motor petroleum in Moscow in 1937 were 155 and 900 rubles per ton respectively

³⁴ Rodionov (2002), 1934 under 14 July and 1936 under 5 July.

³⁵ The maximum range and speed of the TB-7 of 1936 are given by Gunston (1995), 280-1, as 3000 kilometres and 403 kilometres per hour at an altitude of 8000 metres, but no aircraft could achieve both at the same time. A cruising speed of 350kph would suggest a maximum flying time of 8 hours 35 minutes. The TB-7 of that time had four M-34FRN engines totalling 3600 nominal horse power but for cruising speed say 3200hp, making a maximum flight total of just over 27 400 horse-power hours. The TB-7 carried 8250 kilogrammes of fuel (Gunston, 1995, 280-1), making roughly 300 grammes of fuel consumed per horse-power per hour. Thanks to Keith Dexter for advice.

towards its goal so that subsequent refinancing decisions could be taken in the light of more information than was available initially.

Such competition was not normal elsewhere in Soviet industry. In civilian branches funding principals and agents were more likely to form closed bilateral relationships. This did not rule out parallel projects or duplication of work, but it did ensure that organisations working on related issues did not necessarily compete with each other and might not even be aware of each others' work; thus producer interests took priority over the consumer.³⁶ In the defence industry, in contrast, the government acted on behalf of a powerful consumer, the defence ministry, by assigning similar specifications to rival design bureaux; the latter were then forced to compete for their designs to be adopted. This practice was pioneered before the war in aircraft and aeroengine development.³⁷ As will become apparent, however, the intensity of competition was varied through time. Indeed, after World War II it was suggested to Stalin that the Soviet Union was lagging in aircraft and aeroengines because relationships between the air force and the leading aircraft design bureaux had been or had become too cosy, enabling favoured designers to establish monopolies and relax the pace of development. This was one source of the "aviators' affair" of 1946 in which leaders of the air force and aircraft industry were arrested and imprisoned.³⁸

By rationing limited finance across competing projects and through time the principal could exploit agents' rivalry, but rationing also carried important costs. Rationing through time had the effect of softening budget constraints on individual projects because, in the presence of sunk costs, a project could attract refinancing even when it was known to be bad. Because some costs were already sunk, it could still be efficient for both the funding principal and the R&D agent to continue a project that the principal would have preferred not to finance in the first place.³⁹ Rationing across projects brought the danger of a fragmentation of effort in many rival projects, all underfunded. Both types of rationing invited agents to invest resources in lobbying to soften constraints and use the argument that costs have already been sunk as an argument for project continuation.

Financial constraints on projects in progress therefore tended to become soft, and occasionally this became explicit. The technical council of the chief administration for the aircraft industry met in August 1936 to review the development of a number of steam turbine projects. The deputy minister for heavy industry Mikhail Kaganovich presided (this was the brother of the more famous Politburo member and Stalin's deputy Lazar Kaganovich; in the passage below he refers to his boss, minister for heavy industry G.K. "Sergo" Ordzhonikidze, also a member of Stalin's inner team). One of the designers present reported: "they told me [that] to carry out the testing of the turbine in our factory funds of the order of a million rubles [were] needed". Kaganovich interrupted: "I can provide it". Kaganovich told another designer to proceed if he could to a flight test: "Whatever it costs I'll pay". He summed up:⁴⁰

³⁶ Berliner (1976), 120–7

³⁷ Holloway (1982a), 317–19.

³⁸ Bystrova (2000), 320–1. This was not the only source of the purge; according to Pikhov (1998), 45–7, Stalin also designed it to undermine the position of the leader of the war effort Marshal G.K. Zhukov.

³⁹ Dewatripont and Maskin (1995) propose centralised credit and sunk costs as the general explanation of soft budget constraints and shortage phenomena in a socialist economy.

⁴⁰ RGAE, 8328/1/824, 40, 51, 52ob (22 August 1936).

I am not so poor, we have money in the sums that are needed, the boss is not hoarding it, comrade Ordzhonikidze says to take what you need.

What were the consequences of a soft budget constraint? The soft budget constraint might seem like a good thing for technical progress at first sight because the chances of successful invention would appear to increase with the number of generously funded projects. However, a soft budget constraint probably also encouraged adverse behavioural responses. Hanson and Pavitt have noted a tendency of government-funded R&D to generate “too few technical alternatives”; this is because, when budget constraints are soft, R&D agents display too little care in coming to conclusions. They “do not apply the normal, prudent practice of commercial firms in carefully exploring technical alternatives in order to reduce technical and commercial alternatives. Instead, they tend to follow a high risk strategy of premature commitment to the full scale commercial development of a particular technical configuration, before the reduction of key technical and commercial uncertainties”.⁴¹ In other words, uncertain outcomes are not a good reason to throw money at a problem.

Rationing and soft budget constraints help explain an institutional cycle that accompanied Soviet progress in new aeroengineering technologies in the interwar years.⁴² The first phase was one of exploration. For the first time the principal defined the mission and agents formed a lobby. As a result cash was allocated and initial funding was dispersed among agents. With first results, existing projects were refinanced and further projects were designated. At a certain point the principal lost patience with rising expenses and lack of results, and declared a need to concentrate efforts and focus them more narrowly. For example in August 1936 Kaganovich wrote to the Council for Labour and Defence (STO) with Ordzhonikidze’s support to unify all work on steam and gas turbines under his chief administration for the aircraft industry.⁴³

Exploration now gave way to rationalisation. In the rationalisation phase funding was removed from those projects judged less successful, which were terminated, and was concentrated on fewer projects reflecting more limited priorities. Agents responded both defensively and aggressively. Then the cycle was repeated because in the course of rationalisation the principal made mistakes, curtailing some good projects as well as bad ones. Therefore, rationalisation was often temporary because agents would eventually mount challenges to central priorities and organisational monopolies from below and exploration would begin again. However, steam propulsion was only explored through one such cycle.

3.2. The Financing Decision

On the demand side of the financing decision were the *funding principals*. The fundholder and the funding department were not necessarily the same. The *fundholder* was the legal owner of the R&D assets, usually an industrial ministry, but the Red Army also maintained its own R&D establishments. The *funding department* paid for R&D services. Some centralised orders were paid directly out of the USSR state budget. In addition, budgetary institutions such as the defence commissariat were entitled to enter into decentralised contracts with industrial institutes and design

⁴¹ Hanson and Pavitt (1987), 46. Why may hierarchies accept more bad projects than a market system? Hanson and Pavitt’s reasoning proposes that a hierarchy generates specific incentives and is therefore made on different grounds from that of comparative “architecture” proposed by Sah and Stiglitz (1986).

⁴² See also Harrison (2001b).

⁴³ Rodionov (2002), 1936 under 3 August. Evidently, this request failed.

bureaux for R&D services. Finally, the fundholder could also commission in-house research from its own establishments.

Both fundholders and funding departments operated within a framework of strategic directives that were issued from time to time by high-level government committees: the Council for Labour and Defence or the executive subcommittee of the Council of People's Commissars responsible for defence matters. In practice, regardless of the formal issuing authority, Stalin personally made such decisions in secret consultation with a varying circle of individual Politburo members, usually after receiving representations from the funding department and fundholder.⁴⁴

Within this framework both funding departments and fundholders formulated operational plans. The most important planning horizon was annual. The Red Army had an annual plan for the development of military inventions some of which it funded directly through its own R&D establishments and some of which it contracted out to other organisations. Industrial ministries, including the branches of the defence industry, had their own R&D plans. This included the aircraft industry's annual plan for aeroengine research and experimentation to be carried out by its own institutes and bureaux, part of which was made up by contracts accepted from the Red Army.

How did projects win a place in the plan? There was a variety of routes, but their common feature was that the initiative lay with the designer. This was not a process whereby all-seeing and all-knowing planners identified needs from above, sought out designers, and put them together with resources to meet the needs identified. Rather, proposals came first from below. Established designers continually brought proposals for radical innovations to the attention of funding principals; it was their job to do so. For example, here is deputy minister for the aircraft industry M.M. Kaganovich again in August 1936:⁴⁵

Three years ago comrade Tsvetkov came to me and proposed making such a turbine, I went to the boss, the people's commissar signed a decree to the effect that, in urgent order, under personal responsibility, [inaudible] to build a turbine [...]

Successful proposals required investments in lobbying. Such investments could bring not only success for individual proposals but also long-term privileged relationships with government officials responsible for funding. To win support for their projects and adoption of their designs, designers had to be "heterogeneous engineers" capable of reshaping organisational as well as technological constraints.⁴⁶ To create a demand for new designs they had to build coalitions with soldiers or industrialists to overcome producer and consumer interests vested in markets for products that already existed.

Much has been written about Marshal M.N. Tukhachevskii, Red Army chief of armament from 1931 to 1936, as the military patron of jet propulsion in the Soviet Union between the wars. In November 1929 the post of chief of armament of the Red Army was created to help carry through its equipment modernisation. The first chief of armament was Army Commander I.P. Uborevich, followed in 1931 by Army Commander, later Marshal M.N. Tukhachevskii. Among the departments reporting to the chief of armament was an administration for military inventions. In 1936 the post of chief of armament was abolished, its place taken by a chief administration for

⁴⁴ Rees (2001).

⁴⁵ RGAE, 8328/1/824 (22 August 1936), 35.

⁴⁶ On heterogeneous engineers see MacKenzie (1996), 13, and Harrison (2001b) for further illustration.

supply of weapons and equipment, and under the latter a department for inventions.⁴⁷ For reasons that are largely unrelated to this topic Tukhachevskii was arrested in May 1937 and, along with many other officers, subsequently executed as a traitor.⁴⁸

An assiduous networker, Tukhachevskii used his oversight of military R&D to forge exclusive links with designers and acquire a monopoly of jet propulsion development for both artillery and aviation as both funding principal and fundholder. In this ambition he was never successful. But it is notable that the first projects in steam propulsion were also sponsored by establishments of the Red Army, one of them (KB-2) directly under Tukhachevskii's control as chief of armament at the time.

One way of weighing the problem of the principal is to ask what was their most important difficulty: was it to *promote*, or to *limit* the number of projects involving steam propulsion? The clear-cut answer to this question is that the funding principals struggled continually to limit and constrain initiatives and proposals from below. Rather than the funding principals having to stimulate activity at lower levels, it was initiatives from below that typically stimulated higher-level interest and found patrons. These initiatives were diverse and flowed from many sources, and were much more numerous than initiatives from above. As a result R&D projects had a tendency to proliferate that the funding principals found difficult to control. This is reflected in the character of high-level decisions: reports and resolutions prescribing the consolidation or cancellation of existing rival projects greatly outweighed the number of decisions authorising new ones.

3.3. Refinancing

When projects are long term, projects in progress require periodic refinancing. Alternatively, they must be discontinued. By examining refinancing decisions affecting projects in progress we can learn more about the incentives facing designers and funding principals and the calculations they made.

Under the system that I have described, projects arose out of initiatives from below. The role of funding principals was reactive and planning decisions tended to validate these initiatives. Consequently projects in progress were normally refinanced without an explicit decision to this effect being reported. The fact that a project had been previously approved so that initial funds had been disbursed and work begun was a sufficient reason, other things being equal, for funding to be continued.

This raises the possibility that principals were indifferent to R&D failure. Could it be that they distributed project funding to agents in return for political rather than technological payoffs? If so, one could expect the principal to have responded to the agent's failure by emphasising shared objectives, the difficulties intrinsic to the task, the agent's praiseworthy efforts as a foundation for future progress, and the value to the agent of the principal's continued support, together perhaps with the value to society of the experience so far accumulated and other positive externalities. But the evidence does not match this at all. An unusual insight is provided by the ministerial review of continuing steam turbine projects held in August 1936. Kaganovich's mood was one of intense frustration, not indifference to failure; he interrupted the designers repeatedly with heavy sarcasm:⁴⁹

With existing dimensions is it sensible or feasible to place such a plant in an aircraft? One turbine engineer suggested placing 5 turbines in an aircraft, but for this the aircraft must weigh 125 tons without additional payload. You could put a

⁴⁷ Holloway, 1982a, 321.

⁴⁸ On Tukhachevskii and jet propulsion see Holloway (1982b), Siddiqi (2000), and Harrison (2001b). On Tukhachevskii and Red Army rearmament generally see Samuelson (1996 and 2000) and Stoecker (1998).

⁴⁹ RGAE, 8328/1/824 (22 August 1936), 12, 15, 35, 51, and 52 respectively.

F[eliks] D[zerzhinskii] locomotive in an aircraft, but then the aircraft would weigh 2000 tons. This is comrade B[inaudible]’s fantasy, he’s got 245–metre wings and a 45–metre fuselage.

[...] We’re not talking about a boiler on a Tsvetkov *locomotive*. Whoever’s first to give us a turbine, we’ll take it and work with it and the result will be that the airscrew will turn on the ground, if we put an airscrew on a locomotive it’ll also turn, but we need to put it in *an aircraft at altitude* [emphasis added].

[...] Three years ago comrade Tsvetkov came to me and proposed making such a turbine, I went to the boss, the people’s commissar signed a decree to the effect that, in urgent order, under personal responsibility, [inaudible] to make a turbine, [they] began to make it, and now he comes and says: “There’s a turbine but no boiler”. That’s how they move technology forward. It’s as if we got pig–iron but no metal.

[...] I said to comrade Aksiutin [...] I’ll give you a TB–7 airplane, smash it to pieces if you want, but taxi it along, lift it up to 100 metres, and then it will be a deed of proof that a turbine lifts up. Whatever it costs I’ll pay. But [...]

[...] I can’t sit for three years and see no results.

The designers’ response was to plead for time to allow the technology to evolve. They promised to build smaller, more efficient boilers and condensers. The aircraft designers Petliakov and Lavochkin were present. It was obvious that the engines being designed would not fit an existing airframe, so Petliakov asked that the turbine engineers should give more consideration to aircraft design and Kaganovich made him responsible for liaison.

Money and time had been spent, and while there was the smallest possibility of a positive outcome Kaganovich was not going to give up. The costs already sunk meant that the steam turbine projects drifted on for two or three more years. During 1937 a turbine of the Khar’kov Aviation Institute was prepared for installation in a TB–7, but the attempt was recognised to have failed by the end of the year.⁵⁰ One defensive response to the lack of progress was diversification: in January 1938 special–purpose design bureau (SKB) director Sinev referred his superiors to the value of potential spinoffs from his bureau’s work on aviation steam turbines for other branches: naval and locomotive engineering.⁵¹ Only one decision to terminate a project has been found: in July 1938 the Moscow Aviation Institute’s design bureau was closed for failure to progress with the binary cycle turbine.⁵² Other projects simply vanished one by one from plans and reports.

⁵⁰ Rodionov (2002), 1937 under annual prologue and epilogue.

⁵¹ Rodionov (2002), 1938 under 15 January.

⁵² Rodionov (2002), 1938 under 21 July. In the aircraft industry several design bureaux were closed during the Stalin years as a punishment for failure to create successful designs: Albrecht (1993), 136 and 215, lists those of Kalinin, Shcherbakov, Berezniak and Bolkhovitinov, and Gudkov. In some cases the chief designer was imprisoned (Gudkov) or executed (Kalinin).

4. Competitive Threats

4.1. Takeovers and Mergers

An R&D project can be thought of as a long-lived capital asset. All economies need mechanisms for restructuring these assets and transferring ownership through time.⁵³ In the case of R&D projects this mechanism is created by their need for periodic refinancing, which has the necessary effect of creating a secondary asset market. Under Soviet law state ownership rights over R&D project were delegated to ministerial fundholders by whom such rights were not transferable. In reality there were substantial incentives for agents to mount takeover or merger bids for projects of other fundholding departments.

One motive was profit: the predator could compare the value of a project in progress with the costs of taking it over. The value of a project lay in the sunk costs represented by its tangible and intangible assets. These costs had already been incurred at the expense of some other department to whom the new fundholder did not have to pay compensation. Takeovers were costly nevertheless. First, a bid required the payment of direct lobbying costs. Second, it required the expenditure of reputation; a successful bidder made promises for which he might later be held to account. Third, it weakened the ownership rights over economic assets on which all fundholders ultimately relied.

Another motive was competitive threat: it might be more dangerous to abstain from the secondary market than to enter it. For example, small establishments were continually at risk of being swallowed by larger ones. The command system favoured large projects because of their economies of scope: larger units required fewer lines of outside communication and were less reliant on outsiders for essential goods and services. The preference for scale was reflected in frequent calls to eliminate duplication of effort and “parallelism”. Calls for rationalisation and centralisation were rarely if ever questioned; they were regarded as progressive almost beyond debate, especially when comparisons were made with the scale of R&D establishments in aeroengineering abroad.⁵⁴ Smaller units had to expand in order to hold off threats from larger rivals, and one method of expansion was through takeover. Consequently neither large nor small units benefited from restraint, and larger units too were continually on the lookout for opportunities to propose favourable rationalisations of the industry by absorbing smaller ones.

The logic of the takeover bid was a restructuring of liabilities. Consider a failing project, i.e. one that had incurred significant sunk costs without giving results on schedule. Was the project intrinsically bad, or just badly funded or led? If the lack of results compared with the sunk costs could be ascribed to poor resources or organisation, then it was efficient to write off the sunk costs and refinance the project under new management. Such a logic was strengthened when the scope of activity and the number of projects was on the increase because this also brought a rising number of potentially weak projects.

For example in December 1937 special-purpose design bureau (SKB) acting director Sinev submitted a memorandum listing six steam turbine projects in progress in four different institutes and three different cities. Welcoming the piecemeal advances already made, he criticised their “cottage-industry” scope (*kustarshchina*). Claiming the support of his own team and the Khar’kov project leaders, he called for

⁵³ Gregory and Lazarev (2000) provide a study of the Soviet economy’s informal secondary market in another capital good, the motor car.

⁵⁴ RGAE, 8044/1/460, 49–51 (31 December 1940): an explanatory memorandum by People’s Commissar for the Aircraft Industry A.I. Shakhurin on the 1941 plan for aeroengineering research and experimentation.

all the groups to be brought together in a single “unified production–experimentation base” in Moscow, with close links to the aircraft industry.⁵⁵

Another channel for proposals for concentration at this time was the system of peer review. Thus late in 1937 the gas turbine designer V.V. Uvarov of the All–Union Thermal–Technical Institute (VTI) was commissioned to report to the commissariat of the defence industry on the progress of the “gas–steam turbine” being developed at factory no. 18 by designers Dybskii and Udod. After commenting on the weaknesses that he had observed, Uvarov commented:⁵⁶

the continuation of work on the lines under investigation should be curtailed, the more so since work on steam and gas turbocompressors is already going on [elsewhere]. *These two lines [of work] completely cover the authors’ design, and for this reason duplication will yield nothing new.*

4.2. Defensive Measures

One way in which R&D agents defended projects in progress against competitive threats was by creating and reinforcing monopolies in new explicit knowledge. Implicitly, designers did not trust or sufficiently value existing rights of authorship under Soviet law. They sought to prevent rivals from grabbing new knowledge to underpin competing proposals for development funding. Such rival projects would have looked “good” because they would not have had to account for costs of experimentation already sunk.

For example, at the August 1936 ministerial review of steam turbine projects it became apparent to Kaganovich that some barriers against the collaboration among designers that he desired were created by the designers themselves, supported by their departmental superiors. Development work for the Aksiutin turbine was proceeding at the Leningrad Kirov factory (LKZ), but without results. Why had engineer Vinblad failed to make himself useful to Aksiutin on the LKZ site? Because no one would issue him with a pass. Why not? A participating engineer commented: “[..] because there was rivalry, a special proprietary interest [*opeka*] of each in this business. Each was trying to turn this business into one [associated with] his own name”.⁵⁷ In response, Kaganovich was simultaneously reassuring and threatening:⁵⁸

I will take all measures to protect the authorship of one or another comrade at work. If it’s Aksiutin’s turbine so let it be, but if he’s up to some fabrication, and not up to realising a technical solution to the problem, and for this reason has kept Vinblad away from the installation for a full year, then that is an obvious criminal act and an obvious detriment to the value of the turbine for our work.

In our country there are no secrets and the designer who holds on to big secrets and does not carry them out into life — in the capitalist world he would simply perish and in the socialist [world] he is simply good for nothing. That’s why we will set in train all measures and powers to help you realise the ideas and creativity that you have performed, while you are guaranteed full protection of authorship.

Designers also defended themselves against hostile takeovers by lobbying. For example in 1938 a new struggle arose for control over the development of aviation

⁵⁵ RGAE, 8328/1/992, 14–18 (19 December 1937).

⁵⁶ RGAE, 8328/1/996, 22–24 (1 January 1938): emphasis added.

⁵⁷ RGAE, 8328/1/824 (22 August 1936), 38.

⁵⁸ RGAE, 8328/1/824 (22 August 1936), 35, 52.

steam turbines: yes, this was still “work in progress”, and the lack of results was being attributed not to intrinsic badness of the project but to dispersion of resources and duplication of effort. In June the commissariat of the defence industry submitted to Molotov its long-delayed draft plan for aeroengine experimentation for that year. It proposed that all work on aviation steam turbines should be concentrated in the Central Boiler and Turbine Institute (TsKTI) belonging to the electricity generating industry in Leningrad and that a grant of 2.5 million rubles should be made to TsKTI to expand its plant and equipment for this purpose.⁵⁹ On the defensive this time, SKB director Sinev wrote to Molotov, the Kaganovich brothers (one the commissar for the defence industry, the other the responsible central committee secretary), and defence commissar Voroshilov to protest this recommendation.⁶⁰ Sinev made three charges against TsKTI: it lacked an “aviation culture”; it was ineffective even at its primary task, the design of steam turbines for power stations; and it was already “over-encumbered” (*gromozdkaia*). Again he proposed the formation of a new bureau in Moscow based on one from a range of existing aviation establishments.

On this occasion the defence failed; it was referred to air force chief Loktionov, who rejected it and upheld the recommendation in favour of TsKTI.⁶¹ And as table 1 shows 1938 saw the end of aviation steam turbines at SKB. On the other hand the victory of the electricity supply engineers of TsKTI was hollow, because steam aviation was going nowhere and all such projects had been closed down by the end of 1939. In the end, after spending tens of millions of rubles, everyone had to recognise that these were just *bad projects*.⁶²

In early 1939 the Red Army evidently made a decision to close down a wide range of projects in ammunition R&D, not just those concerned with aviation jet propulsion, but including the work it was funding in KB-7. According to reports made to ammunition commissar I.P. Sergeev, and forwarded by him to deputy defence commissar G.I. Kulik, navy commissar M.P. Frinovskii, and prime minister V.M. Molotov, the aggregate plan for ammunition research and experimentation for 1939 had been agreed among these commissariats and with the General Staff the previous year.⁶³ However, in the course of disaggregating the plan and agreeing individual contracts with R&D establishments, the Red Army had unilaterally reneged on commitments worth 40 million rubles (out of 52.5 millions) and the Navy on 7.5 millions (out of 25 millions). Even after immediate cutbacks, 25 million rubles worth of research and experimentation remained without a sponsor, including two institutes that were entirely without funding, one of which was KB-7; among those projects without funding at NII-3 were the Korolev-Glushko rocket glider and a ramjet project. By the end of the year KB-7 had been closed down.⁶⁴

In one sense this decision might be thought timely: in other countries research on steam power for aviation continued for a while. A roundup of steam turbine projects still in progress in approximately 1943, published by *Flight* magazine in London, identifies three. Two American projects continued, one at Great Lakes Aircraft, and the other at United Aircraft in the name of the helicopter pioneer Igor Sikorsky and

⁵⁹ RGVA, 4/14/1925, 232–248 (26 June 1938).

⁶⁰ RGVA, 4/14/1925, 150–152 (17 May 1938).

⁶¹ RGVA, 4/14/1925, 155 (19 May 1938).

⁶² And Sinev was arguing for 10 million rubles *more*. RGAE, 8328/1/992, 15 (19 December 1937).

⁶³ RGAE, 8162/1/299, 36–54 (March to April 1939). Commissar Sergeev was unconnected with the engineer Sergeev previously mentioned.

⁶⁴ Siddiqi (2000b), 31.

others. A London company, Aero Turbines, was continuing work based on the German Hüttner turbine.⁶⁵

In other countries research on steam power for aviation continued for a while. A roundup of steam turbine projects still in progress in approximately 1943, published by *Flight* magazine in London, identifies three. Two American projects continued, one at Great Lakes Aircraft, and the other at United Aircraft in the name of the helicopter pioneer Igor Sikorsky and others. A London company, Aero Turbines, was continuing work based on the German Hüttner turbine.⁶⁶

5. Good and Bad Projects

The problem of the principal was how to select and monitor long lived projects of uncertain worth. In the presence of sunk costs there was a tendency for both the funding principal and the R&D agent to be motivated to continue projects that the principal would have preferred not to finance in the first place. The result was that selection could become adverse: R&D agents were motivated to understate needs and overstate expected returns so as to obtain the first instalment of funding. Once the first instalment was paid and had become a sunk cost, the payment of the next instalment became more likely. Moreover, if results fell short when refinancing became necessary, the designer could always shift blame to the funder since the first instalment of funding was always less than the amount originally proposed.

What factors determined whether a project was “good” or “bad” from the point of view of the national mission? This depended on four factors: the as-yet-unknown state of nature, the level of funding, the organisation of resources and teamwork, and the motivation of the design team. First, the state of nature determined whether or not the project was intrinsically bad. Second, even for an intrinsically good project the level of funding needed to be appropriate to the task. Third, the physical and human resources employed on the project required effective organisation, including teamwork and leadership; a design team that lacked the right equipment or was poorly led would give poor results. Finally, success depended on motivation: what was good or bad depended on whether the state saw it the same way as the designer. Thus some inventors involved in jet propulsion R&D may have been motivated otherwise: to realise a dream, to build an empire, to live in style, or to live in peace. In 1937–8, official suspicions of “other” motivation were sometimes hardened into the designation “enemy of the people”. It is not necessary to go to this extreme to accept that R&D agents’ motivations were not necessarily aligned at all times with the preferences of the state.

When a project failed, did it matter whether it was intrinsically bad, or potentially good but poorly funded or organised? With funding rationed and entry controlled, the danger was that bad projects might drive out good ones. Therefore the funding authorities made great efforts to diagnose the causes of project failure to see if they could be rectified. However, it was also extremely difficult, and perhaps impossible, to do so without hindsight. Even with hindsight it is still very difficult, and for this reason I avoid comment on the intrinsic goodness or causes of failure of individual projects. Only classes of project can be evaluated in this way; for example, all the

⁶⁵ Smith (no date), 36–40. According to the same authority Breguet Aviation in France was known to be still working on a reciprocating aeroengine supercharged by a steam turbine in 1942. For a Soviet project begun on similar lines in the early 1930s but soon abandoned, see footnote 29.

⁶⁶ Smith (no date), 36–40. According to the same authority Breguet Aviation in France was known to be still working on a reciprocating aeroengine supercharged by a steam turbine in 1942. For a Soviet project begun on similar lines in the early 1930s but soon abandoned, see footnote 29.

aviation steam turbine projects were intrinsically bad, but I do not know which ones were also poorly funded or poorly led.

The various research establishments reported regularly to higher authority on each project in progress. From time to time the same authorities launched special reviews which ranged from round-table exchanges of specialist opinion concerning common difficulties shared by several projects, and specific investigations of specific projects thought to be at risk of failing.

The difficulty of establishing the causes of project failure made it easy for designers to displace the blame for their own lack of success. As has already been shown, designers sometimes faulted the funder for dispersing funding too widely, that is, sharing it with rival projects: they argued that more time and more focused funding would turn their own project round. Designers also blamed producers for failure to share the motivation of the design, leading to incompetent or neglectful preparation of components and assemblies. For example, the steam turbine designer Aksiutin complained to Tukhachevskii in 1935 that the Leningrad Kirov factory (LKZ) was incapable of playing a constructive role because it was gripped by “a certain conservatism utterly alien to the aviation culture” and commented that LKZ had declined a contract to build an Uvarov turbine for VTI giving as its official reason that the turbine required “too many parts to be completed to ‘aviation standards’ that would be an embarrassment for the factory [*chto dlia zavoda zatrudnitel’no*]”.

According to the recollection of the aircraft designer A.S. Iakovlev, Stalin himself reflected on the tendency of designers to displace the blame for their own lack of results:

A designer is a creative worker. Like the painter of a picture or the writer of a literary work, the product of a designer’s or scholar’s creativity can be successful or unsuccessful. The only difference is that from a picture or verse you can tell the author’s talent right away. [...] With a designer it’s more complicated: his design can look very attractive on paper, but final success or failure is determined much later as a result of the work of a numerous collective and after the expenditure of substantial material means ... Most designers get carried away with themselves and are convinced of their own and no one else’s righteousness; on the basis of an overdeveloped self-regard and the mistrust that is characteristic of every author they tend to attribute their own failures to prejudice against themselves and their creations.⁶⁷

Were the different intrinsic motivations of R&D agents a factor in project success and failure? Stalin understood that Soviet funding institutions offered a degree of protection for self-serving interests; this created a rationale for him, with his security chiefs N.I. Ezhov, then L.P. Beriia, periodically to mount cruel inquisitions into the souls of the scientists and engineers.

It is not clear whether the steam turbine engineers escaped the general bloodletting in 1937–8.⁶⁸ The MAI experimental design bureau was closed down but the fate of its steam turbine designer Przheslavskii is not known. SKB director Sinev went on to become deputy chief designer at the Leningrad Kirov factory (LKZ) in wartime, subsequently director of the LKZ experimental design bureau, and a leader

⁶⁷ Iakovlev (2000), 501.

⁶⁸ The relationship between success, failure, and punishment in the Great Terror was complex. See Manning (1993).

of the postwar uranium industry.⁶⁹ And Aksiutin reappeared in Voronezh in 1947–8 as chief designer of an experimental aeroengine design bureau in factory no. 154.⁷⁰

The only known victim of repression is A.Iu. Vinblad, chief of the Leningrad Kirov factory special-purpose design bureau for turbine engineering and a participant in the August 1936 ministerial review of steam turbines. He was arrested in February 1940 and sentenced to eight years in a labour camp. In September 1942 he was transferred to a scientific penal colony where in May 1946 he was listed as working on a jet aeroengine.⁷¹ Had he taken blame for a steam power project failure? Vinblad was sentenced for espionage under Article 58(6) of the RSFSR penal code; most likely he had been careless with his paperwork, had travelled abroad, or had communicated with relatives abroad. Had he been punished for an R&D failure, he would more likely have been charged with economic sabotage under Article 58(7).⁷²

Finally, given that the steam turbine projects were bad ones, what further light has been thrown on the possibility that principals deliberately tolerated or fostered them in order to distribute rents? Evidence that the funding of steam turbine projects was continued despite evidence of failure in order to promote vertical relationships of trust and loyalty has not been found. Their continued refinancing is sufficiently explained by sunk costs and the difficulty of diagnosing the causes of project failure. By western standards the Soviet termination of steam turbine projects in 1939 was timely. Two or three years after this, for example, when the jet engine was already proven in flight, expert opinion in the west had still not finally written off the prospects of steam power for aviation.⁷³ Evidence from other fields of Soviet military R&D also confirms that, when rent-seeking was identified, it was punished.⁷⁴

6. Conclusions

During the 1930s the Soviet Union probably invested more resources in steam power R&D than in jet propulsion or rocketry, and possibly as much as all other countries put together. An investigation of the results suggests a number of findings of more general significance.

⁶⁹ Lebina (2000), 188.

⁷⁰ RGAE, 8044/1/1637, 112 (12 June 1947) and 8044/1/1795, 109 (May 1948).

⁷¹ GARF, 9401/2/136, 207 (18 May 1946). This person, called both Vinblad and Vinblat in the verbatim record of the August 1936 ministerial review, is Vinblad in the presently cited report by a senior MVD official, but Vinblat in an accompanying memorandum by minister S.N. Kruglov (*ibid.*, 204). Both documents were addressed to Stalin personally. One hopes the latter was not in a mood to see sabotage in misspelling.

⁷² Article 58, which dealt with “counter-revolutionary crimes”, is reproduced in part by Conquest (1971), 741–6. Since Vinblad’s sentence exceeded 3 years he must have been convicted of “transmission, theft or collection” of “an *especially guarded state secret*” (my emphasis) with a view to handing it to “foreign states, counter-revolutionary organisations, or private individuals”, but not involving “*especially grievous* consequences to the interests of the USSR” which would have merited death by shooting. The reference to private individuals means that suspicious personal contacts could have constituted evidence sufficient for a conviction. In contrast the rocket aircraft designer S.P. Korolev, arrested in June 1938, was imprisoned under Article 58(7) (economic sabotage), 58(8) (terrorism), 58(11) (premeditation and conspiracy), and 58(17) (political sabotage); see Raushenbakh (1998), 64–6.

⁷³ Smith (no date), 36.

⁷⁴ Harrison (2001b).

1. In the Soviet Union steam power R&D was carried out in the context of a vertically organised command system. Within this context there was a great deal of market-like activity on the supply side including horizontal rivalry and competitive rent-seeking, a secondary market in R&D projects involving takeover and merger activity, and attempts to create and defend monopolies.
2. In the Soviet command system the designer took the initiative. There was no shortage of inventiveness and there were more proposals for radical innovations than the authorities were willing to fund. The main problem for the authorities was to control, not to promote inventive activity.
3. In the Soviet economy the scale of steam power R&D was that of an artisan industry. The resources available for such research were extremely limited and funding was rationed. However, budget constraints on individual projects in progress tended to become soft. Once a project had been selected for funding it had a good chance of its funding being continued until aggregate limits on the funding principals' resources and patience were breached.
4. Designers who were successful in getting their proposals selected for initial funding and subsequent refinancing were "heterogeneous engineers". They invested resources in lobbying and political reputation to ensure that their projects were selected for funding and, once selected, to protect them against termination from above or takeover by rivals in the name of rationalisation.
5. It was difficult or impossible for the authorities to tell good ideas from bad ones. The difficulty beforehand reflected technological uncertainty and agents' unobserved characteristics. It was not much less difficult when projects were in progress because projects could fail for reasons unrelated to the goodness of the original idea. In the presence of sunk costs, refinancing a project in progress was usually easier than terminating it. It is possible that adverse selection resulted.
6. There is no evidence that rents were intentionally distributed through the Soviet military R&D system to win trust or reward loyalty; the termination of aviation steam power R&D in 1939 despite the sunk costs they represented was timely.

Table 1. Major Soviet R&D Projects for Aviation Steam Turbines, by Establishment, 1932 to 1939

	1932	1933	1934	1935	1936	1937	1938	1939
1. KhAI	Tsvetkov 15 000hp turbine—————				Tsvetkov “air-naval” PT-6 (6000hp)————— PT-6 (3000hp) —————			
2. NII GVF	PT-3 (3000hp) “air-naval” steam turbine—————							
3. VVA	Aksiutin PT-1 (1500/2500hp) turbine (continued at SKB and Energeticheskii institut)							
4. SKB	Sinev turbine					Sinev 1600/2500hp turbine————		
5. EI						Aksiutin turbine (from VVA) —————		
6. KB-2	Kozhevnikov 400hp gas-steam turbine—————							
7. VTI					“Air-naval” 1000hp turbine	Przheslavskii 2000hp binary-cycle steam turbine————		
8. MAI							—————	
9. TsKTI						Hüttner turbine	VT-1, VTK-100 (100hp), and VTK-3000 (3000hp) turbines	PT-1M (2000hp) and VTK-300 (100hp) turbines
10. Zavod no. 18						Dybskii-Udod gas-steam turbine—————		
11. TsIAM								1600hp, single-, and binary-cycle turbines

Sources and Key to Design Establishments: see next page.

Sources for Table 1

The supporting documentation comprises plans, reports, and memoranda of the People's Commissariats of Defence, Heavy Industry, the Defence Industry, and the Aircraft Industry: RGAE, 8044/1/994, 21–23; 8328/1/696, 25; 8328/1/824, 1–50; 8328/1/919, 84; 8328/1/992, 6–7; 8328/1/996, 16–18, 22–23ob. RGVA, 4/14/2800, 4; 34272/1/167, 23–24, 47–55, and 102–119. See also Rodionov (2002), 1932 under the month of September, 17 Sept., and 31 Dec.; 1933 under 10 Feb. and 8, 21, and 23 March; 1934 under 3 and 14 July.

Key to Design Establishments

1. **KhAI** (Khar'kovskii Aviatsionnyi institut NKTP–NKOP–NKAP): Kharkov Aviation Institute of the People's Commissariat of Heavy Industry (later Defence Industry, later Aircraft Industry)
2. **NIIGVF** (Nauchno–Issledovatel'skii institut Grazhdansko–Vozdushnogo Flota GUGVF SNK): Research Institute of the Civil Air Fleet of the Chief Administration of the Civil Air Fleet of the Council of People's Commissars
3. **VVA** (Voenno–Vozdushnaia Akademiia RKKA): Air Force Academy of the Workers' and Peasants' Red Army
4. **SKB**, later **SKB–1** (Spetsial'noe Konstrukorskoe biuro Pervogo Glavnogo upravleniia NKOP): Special-purpose Design Bureau of the First Chief Administration of the People's Commissariat of the Defence Industry
5. **EI** (Energeticheskii institut AN SSSR): Energy Institute of the USSR Academy of Sciences
6. **KB–2** (Konstrukorskoe biuro no. 2 UVI RKKA): design bureau no. 2 of the Administration of Military Inventions of the Workers' and Peasants' Red Army (Leningrad)
7. **VTI** (Vsesoiuznyi Teplotekhnicheskii institut im. Dzerzhinskogo NKTP): Dzerzhinskii All-Union Thermal–Technical Institute of the Electricity Supply Industry Administration of the People's Commissariat of Heavy Industry
8. **MAI** (Moskovskii Aviatsionnyi institut NKTP–NKOP–NKAP): Moscow Aviation Institute of the People's Commissariat of Heavy Industry (later Defence Industry, later Aircraft Industry)
9. **TsKTI** (Tsentral'nyi Kotlo–turbinnnyi institut Energoproma NKTP): Central Boiler and Turbine Institute of the Electricity Supply Industry Administration of the People's Commissariat of Heavy Industry (Leningrad)
10. **Zavod no. 18** (zavod no. 18 NKOP): factory no. 18 of the People's Commissariat of the Defence (later Aircraft) Industry
11. **TsIAM** (Tsentral'nyi Institut Aviatsonnogo Motorostroeniia NKTP–NKOP–NKAP): Central Institute for Aeroengine Building of the People's Commissariat of Heavy Industry (later the Defence Industry, later the Aircraft Industry)

Table 2. The Number of Major Soviet Projects for Aeroengines Based on Jet Propulsion and Turbines, 1 January 1932 to 30 June 1941

	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941(1)
<i>Steam Turbines</i>										
1. In progress at start of year	0	3	4	4	3	2	6	1	0	0
2. Starting during year	4	1	0	1	0	4	0	1	0	0
3. Continuing during year	4	4	4	5	3	6	6	2	0	0
4. Discontinued by end of year	-1	0	0	-2	-1	0	-5	-2	0	0
5. In progress at end of year	3	4	4	3	2	6	1	0	0	0
<i>Gas Turbines, Jets, and Rockets</i>										
1. In progress at start of year	0	1	1	1	1	3	3	3	6	4
2. Starting during year	2	0	1	0	2	1	1	5	0	3
3. Continuing during year	2	1	2	1	3	4	4	8	6	7
4. Discontinued by end of year	-1	0	-1	0	0	-1	-1	-2	-2	0
5. In progress at end of year	1	1	1	1	3	3	3	6	4	7

Source: this table is adapted from Harrison (2001b), table 2. For steam turbines specifically see table 1 of this paper. I count as one “major project” work that is continued in one establishment from year to year even though the particular objects may vary, and also work that is continued on a particular object from year to year by one designer even though the sponsoring establishment may change. Row 1 equals row 5 in the preceding year; row 5 is the sum of rows 4 and 3; row 3 is the sum of rows 2 and 1.

Table 3. Soviet Designs for Aviation Steam Turbines: Technical Characteristics.

Design establish- ment	Designer	Model	Capacity, horse- power	Weight, kilo- grammes	Specific weight, kilo- grammes per horse- power	Specific fuel consump- tion, grammes per horse- power per hour
KhAI	Tsvetkov		15 000	16 500
KhAI	Tsvetkov	PT-6	6 000 reduced to 3 000	9 600 reduced to 3 000
NII GVF	..	PT-3	3 000	3 000
TsKTI	..	PT-1M	2 000	..	1.0	300
SKB	Sinev	..	1 600 increased to 2 500	..	2.5	350-400
VVA- SKB- E.Inst	Aksiutin	PT-1	1 500 increased to 2 500	..	1.0	220
VTI	..	“Air- naval”	1 000	1 000
KB-2	Kozhev- nikov	..	400	..	0.65 ^a	..

Sources: as table 1.

Note^a Excluding the weight of a gas turbocharger.

Appendix. The Besler Connection

A Travel Air 2000 biplane made the world's first piloted flight under steam power over Oakland, California, on 12 April 1933. The strangest feature of the flight was its relative silence; spectators on the ground could hear the pilot when he called to them from mid-air.⁷⁵

The aircraft, piloted by William Besler, had been fitted with a two-cylinder, 150 horse-power reciprocating engine. An important contribution to its design was made by Nathan C. Price, a former Doble Steam Motors engineer; When Doble went bankrupt in 1931 William Besler and his brother George bought its assets and patents and founded the Besler Corporation. At Besler Price was working on high pressure compact engines for rail and road transport; the purpose of the flight was to obtain publicity for this work. Following its unexpectedly favourable reception Price went to Boeing and worked on various aviation projects, but Boeing dropped the idea of a steam aeroengine in 1936.⁷⁶ Price later worked for Lockheed where his experience with developing compact burners for steam boilers helped to design Lockheed's first jet engine.⁷⁷

On its own the Besler engine weighed 180lbs but the boiler and condenser took the weight up to 500lbs, some 200lbs more than the Curtiss OX-5 engine that it replaced.⁷⁸ The result was a specific weight of approximately 3.3lbs (1.5kg) per horse power, a figure that was high relative to the internal combustion aeroengines of the time, and also some of the Soviet steam turbine designs listed in table 3, but the engine had not been designed for aviation use nor had it been adapted.

The advantages of the "Besler System" that were claimed at the time included the elimination of audible noise and destructive vibration; greater efficiency at low engine speeds and also at high altitudes where lower air temperatures assisted condensation; reduced likelihood of engine failure; reduced maintenance costs; reduced fuel costs, since fuel oil was used in place of petrol; reduced fire hazard since the fuel was less volatile and operating temperatures were lower; and a lack of need for radio shielding.⁷⁹

Not surprisingly Soviet aviation experts became aware of the Besler System. According to a report to defence minister Voroshilov and others dated 3 July 1934, the current plan for experimental aircraft and aeroengines included a steam engine with a capacity of 100 to 120 horse power and weight of 120 to 150 kilogrammes. The chief administration for the aircraft industry had subcontracted the design work to a team at the Moscow Aviation Institute led by a professor Kvasnikov. The report states: "a steam automobile is being purchased abroad as a basis for designing a steam engine for an aircraft".⁸⁰ This appears to have been an engine commissioned from the Besler Corporation.⁸¹

⁷⁵ FitzGerald (1933) reports the flight. I thank Jean Vezina for this and other references and information relating to the Besler experience.

⁷⁶ Schlaifer (1950), 448–9.

⁷⁷ Jean Vezina (personal communication, 14 November 2001).

⁷⁸ Martin (1933) provides a technical description. A replica of the Besler steam engine is on display at the Smithsonian National Air and Space Museum in Washington, DC.

⁷⁹ Martin (1933); Nickerson (1933).

⁸⁰ Rodionov (2002), 1934 under 3 July

⁸¹ Later the Boeing executive Allan Bonnalie stated that the Besler brothers "got a contract from the Russian govt. to build an actual airplane power plant which they

There is no evidence, however, that a Soviet aeroengine ever resulted. One reason may be that the Soviet authorities' primary motivation was to improve the power plant for heavy bombers. For capacities in excess of 1000 horse power a turbine captures the energy released by the expansion of steam more efficiently than a piston. Thus, the steam reciprocating engine turned out to be unsuitable for scaling up to the needs of large aircraft, and interest today in the application of steam power to aviation remains confined to small reciprocating engines.

did". The transcript of this interview, undated but probably done not long after World War II, is in the collection of Jean Vezina. Vezina adds, however: "According to Jim Crank, a retired Lockheed engineer and a renowned steam car collector who had personally known William Besler before his death in 1984, the engine delivered to the Soviet Union was in fact a Doble steam car chassis and not a dedicated airplane powerplant. The Bonnalie statement was not first hand since, at that time, the contract with the Boeing School of Aeronautics was completed and the deal with Russia was made at the Besler factory at Emeryville, California" (personal communication, 18 March 2002).

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